A Review on Destress Blasting as Essential Technique to Control Rockburst in Deep Mines

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***Abstract*: Along with the exploitation of deep mineral resources and the subsequent high concentration of ground stress, the frequent rock bursts occurrence increases consequently, which strongly hinder the safe and economic recovery of deep-seated mineral resources. Due to this greater mining depth followed by the occurrence of rockbursts problem, the application of destress blasting is recently growing as a deep mine safety tool. Destress blasting is one of the essential techniques to control the rockburst hazards in deep mines through the principle of stress transfer. As the main objectives, this paper reviews and discusses the meaning, brief history, and the application, classification, mechanism, influencing factors and Suitable areas for the application of destress blasting, and the possible challenges which may arise during its field application. As the application of destress blasting involves the use of explosives to fracture rocks as a kind of functional blasting, therefore, the destress blasting mechanism, was objectively discussed in this paper, and a certain understanding and ideas for further improvement of the field application of destress blasting technique was gained from this review. It is concluded that, the high stresses concentration in surrounding rock mass of the underground mining working face are decreased after the application of destress blasting.**

Keywords: Destress blasting technique; Rock burst; Deep mine; Ground stress; High stress concentration; Stress transfer

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1.INTRODUCTION

Based on great economic significance of mineral resources for a nation, and the view that shallow resources have been gradually exhausted, their exploitation is currently constantly developing to deep, where mineral resources were not exploited at the beginning of mining industry due to the limitation of early mining techniques and suitable equipment. As positively related, the depth of mining increases with the increase of ground stress (Kouame et al., 2017; Liu and Wang, 2018). With this deep deposit mining and high concentration of ground stress, the subsequent frequency of rock bursts occurrence and other dynamic hazards increase consequently, which strongly hinder the safe and efficient mining (He et al., 2012; Kaiser and Cai, 2012; Chen et al., 2012; Cai, 2016; Feng et al., 2017; Sengani and Zvarivadza, 2017; Kouame et al., 2017). Rock bursts are more pronounced in hard rocks and geological features like dykes and faults, of deep underground deposits exploitation. Rock bursts are more often closely related to high extraction ratios and associated with underground deposits exploitation techniques leading to unfavourable ground stress situations (Kaiser and Cai, 2012).

Maziaira and Konicek (2015) state that, in order to prevent and control rockburst and realize the safe, efficient and economic recovery of deep-seated mineral resources, the methods and tools that mining engineers can use are to adopt proper mining techniques and construction method, ground preconditioning, and ground support and reinforcement to improve the stress distribution state and properties of rock mass.

Different previous studies focus on destressing techniques as the best measure to control rock burst in deep mine. Destress techniques are stress control methods employed in deep underground mine to control rock burst hence ensures the safe and efficient mining. Destressing techniques have been widely used in deep underground mines in South Africa, Canada, USA, China and some of the rest of the world (Tang, 2000). Destressing technique is a method to form a destressed zone in the surrounding rock mass of working face and a stress bearing zone ahead of working face. It has an obvious effect on controlling the stress concentration of surrounding rock mass and preventing rockburst in the surrounding rock mass of the stope by the principle of stress transfer.

Destressing technology can be divided into strategic method and tactical method. The strategic method aims at eliminating the conditions of rockburst and other geological disasters. This method mainly includes the proper mining sequences, reasonable development layout, reasonable stope structural parameters (dimension, geometries) and exploitation rates (O'Donnell Sr, 1999). Tactical methods are designed to maintain and control dangerous areas that have become fractured or have potential geological hazards. This method mainly includes destress blasting, destress drilling, reasonable selection of supporting measures (O'Donnell Sr, 1999) and Water infusion. The destress blasting is the focus of tactical method. Table 1, presenting the destressing techniques (tactical methods) as high stress control techniques in deep mines and other underground civil construction.

Table 1. Destressing techniques (Tactical methods)

Destressing techniques (Tactical methods)	Explanations	Merits
Destress blasting	It is one of the stress control methods employed explosives (refer to Fig.2) to fracture rock mass intentionally, in deep underground mining and excavation to control and mitigate rock burst occurrence by transferring the stress ahead of face	Reducing the stress in the area where rock burst may occur; Transferring the high stress to away from the roadway and stope; Reducing the strain energy of surrounding rock; Reducing the mechanical parameters of rock mass, especially the elastic modulus.
Destress drilling	It is a very successful method of coalburst prevention which has been used in Germany and Russia. The holes burst and fines are removed during drilling until the stress has reduced below bursting levels. It has to be repeated every 5 m or so of advance (Baltz, 2010; Calleja and Porter, 2016).	It is a slow process effective method for low productivity mining; Reducing the stress in the area where rock burst may occur; Transferring the high stress to away from the roadway and stope; Reducing the strain energy of surrounding rock; Reducing the mechanical parameters of rock mass, especially the elastic modulus.
Water infusion	Water infusion is used in coal seams mainly as a standard tool to control rockburst. It was successfully used in the USCB (upper silesian coal basin)	Reducing the stress in the area where rock burst may occur; Transferring the high stress to away from the roadway and stope; Reducing the strain energy of surrounding rock; Reducing the mechanical parameters of rock mass, especially the elastic modulus.

Konicek et al. (2011), put destress rock blasting in the main active rock burst control techniques in surrounding rock mass of the stope. Destress blasting technique was and is being applied to control rock burst in most of the deep underground mines and some other underground civil constructions around the world. In this paper, the Authors focus on destress blasting technique to be reviewed as essential underground mine safety tool.

2. MAIN LITERATURES

2.1. Meaning Discussion of Destress Blasting

Destress blasting technique stress control method or stress relief method. It can also be called pre-conditioning method. By referring to the previous researches, different researchers have made great contribution to find out the definition of destress blasting. According to Gregersen (2006), Destressing blasting is a term used when a mass of rock is purposefully damaged, usually by blasting, in order to affect the stress field in the area of mining, with the intent of reducing or eliminating the stress related problems. According to Hedley (1992), Destress blasting is where the blast fractures the rock and reduces its stiffness which in turn transfers stress to the adjacent rock mass for the purpose of overcoming problems of highly-stressed ground and rockbursts. According to Saharan and Mitri (2011), Destress blasting in one of the tools to improve mines safety and it is one of the most valuable techniques to control the damaging effects of rockbursts. According to Tang (2000), Destress blasting is a rock fracturing technique to stress-relieve potential rockburst zones in deep mines.

From the above literatures, despite the factors which contribute to the increase of ground stress, it is clearly seen that, all definitions focus on ground stress control as the major triggering factor of rockburst in deep mines.

2.2. Brief History of Destress Blasting

The conceptual model of destress rock blasting technique was put forward based on the rockburst model. This model was formed since the second half of 28th century (Konicek et al., 2011a; 2011b; Konicek et al., 2012). It is one of the most crucial method for controlling the threats of strain bursts resulting from the higher stress induced by underground excavation (Konicek et al., 2011a; 2011b; Konicek et al., 2012). Destress blasting was first applied in South African gold mine such as at East Rand Proprietary Mines (ERPM), under the guidance of Council for Scientific and Industrial Research (CSIR) in the early 1950's (Hedley, 1992; Tang, 2000; Konicek et al., 2011; Sengani and Zvarivadza, 2017). In Canada, Ontorio, at Kirkland lake mine, destress blasting technique was used on trial and error basis in the 1930s (Saharan and Mitri, 2011), and its first application was done in the early1950s (Hedley, 1992). In Nova Scotia, it was put in use in the 1930s in deep coal mining (Springhill Colliery) in Czech part of the USCB, the technique has been developed from 1980s. Since the beginning of 1980s, the used destress rock blasts have been exceeded two thousand, and the explosives have been exceeded three and half million tons (Konicek et al., 2011b; Konicek et al., 2012; Calleja and Porter, 2016).

Even if the main purpose of destress blasting was to improve the stress condition of the surrounding rock of the hanging wall, where the fragmentation zone is formed in front of the working face by blasting, which reduces the high stress concentration around working face and reduce the rock burst occurrence and its associated hazards, however it was not commonly approved by mining industry as essential technique to control and mitigate the occurrence of rockburst in deep mines (Toper, et al., 2000). According to this uncommon understanding, the application of technique was stopped for a certain period of time for further research (Hedley, 1992). In period of 1980s -1990s, the research for further use of destress blasting was conducted in South African gold mines, the result from which have been used to approve the application of destress blasting as essential technique for rockburst control in deep mines (Adams et al., 1981; Rorke and Brummer, 1988; Hedley, 1992; Adams et al., 1993; Lightfoot et al, 1996), destress blasting is currently being employed by worldwide mining industry as essential technique for rockburst control (konicek et al., 2011a).

2.3. General Views on Destress Blasting

From many years ago, destress blasting technique have been applied to deal with rock burst problem, some theoretical and experimental research on destress blasting has achieved great results. In the 1950s, the destress blasting technique was first applied in South Africa gold mine with the purpose to improve the stress condition of the surrounding rock (hanging wall rock), by making the fracture zone ahead of the working face by blasting, which reduce the stress in the working face and reduce the rock burst tendency (Hedley, 1992; Tang, 2000; Konicek et al., 2011; Sengani and Zvarivadza, 2017)

Bole and Swanson (1993) conducted a thorough study of destress blasting process by analysing the successful cases of destress blasting at Galena mine to prevent and control rock burst in mines, and gained a certain understanding of its mechanism. Toper et al. (2000) proposed the method of destress blasting with vertical and parallel face, and compared the stress situation in the zone destressed by blasting with that of non- destress blasting. At the same time, the blasting parameters of vertical face destress blasting are optimized. The results of destress blasting after the optimization of parameters are obviously better than that of before optimization. Based on deep analysis of the destress blasting principle of the pillar conducted by Andrieux and Hadjigeorgiou (2008), the parameters of destress blasting were obtained by using mathematical methods combined with the actual situation of Brunswick mine in Canada.

According to Konicek et al. (2011), a well befitted destress blasting (location and spacing of destressing holes, diameter of destressing holes, length of charge, number of destressing holes holes, and the total explosives charge, decreases the strength of rocks and discharges the high stress concentration in the zone closer to the blasting area. In this circumstance, the main objectives of destress blasting proved to be reducing the strength of competent rock strata and decreasing their effective modulus of elasticity, and stress release. With many years of the application of destress blasting technique in hard coal longwall mining in the Czech part of the USCB, have revealed that it is very important applicable technique to alleviate stress in unfavourable high stress condition so as to control rock burst in deep mine (Konicek et al., 2011b).

In China, a destress blasting technique started in the 1980s, but developed rapidly (Liu, 2014). The researcher of Chinese Academy of Coal Sciences, Proposed the measures of deep-hole controlled destress blasting to prevent outburst, which were pioneered in technology and equipment, and reached the international advanced level at that time. The technique has been applied in Jiaoxi Coal Mine of Jiaozuo, and obvious economic and social benefits have been achieved. Cai et al. (2008) proposed the method of shallow hole destress blasting to prevent and control rock burst according to the characteristics of rock burst in a mine roadway, after their thorough study, many demonstrations show that it is an effective method for rock burst prevention and control.

Ren (2010) combined the mechanism of destress blasting with the principle of rock burst, and analysed the main factors affecting the parameters of destress blasting in roadway, such as the degree of joints and cracks, the strength of surrounding rock itself, the direction of destress blasting, the degree of near static fracture and the characteristics of explosives. It is concluded that the surrounding rock with small brittleness and stiffness closed to the failure envelope and high degree of fracture is the rock with ideal destressing effect.

2.4. Specific Application of Destress Blasting

In the history of mining industry, from many years ago up today, destress blasting technique has been applied in different countries to deal with high stress concentration of surrounding rock of face and its consequence as rockbursting in underground mines. Some countries with their corresponding mines applied destress blasting are summarised below.

In Canada

This safety tool for rockburst control is regularly employed in sill pillars in thin, steeply-dipping orebodies such as those at Campbell Red Lake Mine, Dickenson Mine, Kirkland Lake (Maccassa mine) (Cook and Bruce, 1983; Hedley, 1992), Falconbridge Mine (Cook and Bruce, 1983; Hedley, 1992; Saharan, 2004) and Brunswick mine (Saharan, 2004). At Inco's Creighton Mine (Nickel-Copper-Cobalt), destress blasting is also regularly employed in driving development openings, and in pillar and stope faces during the first cut in cut-and-fill mining method (Hedley, 1992). During the 1980's, 4 destress blasts were done with varying degrees of success. The most successful was the destressing of crown and sill pillars on the 18 level in Campbell Red Lake Mine (Hedley, 1992). Full cases studies of destress blasting of the above-mentioned mines are found in Rockburst Handbook for Ontario Hardrock Mines (Hedley, 1992), and in Doctoral Dissertation entitled Rockburst Control Using Destress Blasting (Tang, 2000).

In China

In China, the technique of destress blasting started in the late 1980s, but developed rapidly (Liu, 2014). Tang, (2000), Summarized the destress blasting cases applied in the following chines mines during the exploitation period of deep-seated mineral deposits, these include: Mentougou coal mine, Longfeng coal mine in Fushun, Tangshan coal mine, Tianchi coal mine in Deyang.

In USA

The destress blasting was specifically applied in Luck Friday lead silver mine, owned by Hecla Mining Company in Idaho; Galena mine owned by Coeur d'Alene Mines Corporation and ASARCO in Wallac, Idaho; Lake shore gold mine, etc., (Tang, 2000); Star morning lead silver mine in Burke, Idaho (Tang, 2000; Saharan, 2004)

In South Africa

In South African deep gold mines, destressing technique has been employed many times since the 1950's to maintain the stability of advancing face (Roux et al., 1957; Gregersen, 2006), and has been well documented in terms of both instrumentation results and compared with non destressing cases (Blake et al., 1998; Gregersen, 2006). They are different mines which have applied destress blasting technique to control rock burst, including: East Rand Proprietary Mines (ERPM), Vaal reefs gold mine, Western deep level South gold mine, Libanon gold mine, West Driefontein Gold Mine (WDGM), Blyvooruitzich Gold Mine, etc (Tang, 2000). South African reported destress blasting were more pronounced in sub horizontal, deep, gold reef ores. The reported trials show the evaluation of 2 types of drilling geometry, such as large diameter destressing hole drilled parallel to the advancing mining face, and multiple small diameter destressing hole drilled perpendicular to the advancing face (Tang, 2000; Gregersen, 2006).

In other parts of the world

Since 1980's, destress blasting technique was also initiated in Czech Republic part of the USCB. Since the beginning of 1980s, the used destress rock blasts have been exceeded two thousand, and the explosives have been exceeded three and half million tons (Konicek et al., 2011b; Konicek et al., 2012; Calleja and Porter, 2016). Tang, (2000), Summarized the destress blasting cases applied in the following mines during the exploitation period of deep seated mineral deposits, these include: Pyhasalmi Iron mine owned by Boliden in Finland; Malmberget Iron mine owned by LKAB in Sweden, Laivall Lead mine owned by Boliden; and Besshi copper mine owned by Sumtomo crop company in Japan.

Note: Despite the application of destress blasting, the increase of rock burst occurrence is a severe problem to the engineers and researchers. A well mastering the fractures growth caused by poly axial stress regime and the appropriate use of explosive energy for effective fracture creation and growth are pointed out as important attention to enhance destress blasting technique (Saharan and Mitri, 2011; Konicek et al., 2011). It is substantiated that destress blasting is the best reliable proactive means to control the threats of rockburst if reasonably employed in real place, manner and timing. The results of destress blasting technique can be very good if the proper way of its application is mastered and it is considered to be a very important and necessary part of regular mining cycle as the objective of destress blasting is to create a safety barrier between the excavation boundary and the high stress zones (Mitri, 2000; Saharan and Mitri, 2011).

3.CLASSIFICATION OF DESTRESS BLASTING ACCORDING TO THE WAYS OF APPLICATION

It is known that the application of destress blasting involves the use of explosives as a kind of functional blasting, so according to the ways of application, destress blasting can be classified into different categories as shown in Table 2.

Table 2: Classification of Destress Blasting According to the Ways of Application

Point of reference	Classification	Description and Effects
Length of destressing holes	Long (deep) destressing hole blasting	Depth of destressing hole is generally greater than 5 m
	Shallow destressing hole blasting	Depth of destressing hole is generally less than 5 m
Effect of	Complete destress blasting	The most well performed destressing state. Reducing the stress in the area where rock burst may occur; Transferring the high stress to away from the roadway and stope; Reducing the strain energy of surrounding rock; Reducing the mechanical parameters of rock mass, especially the elastic modulus.

destressing	Incomplete destress blasting	Cannot completely relieve the high stress in surrounding rock, and may cause further instability of surrounding rock, resulting in rock burst and other ground pressure problems.
	Over destress blasting	The energy of blasting is greater than the energy required for relieving the stress, which leads to the instability of the working face.
Number of Destressing holes	Single destressing hole blasting	Used to solve the problem of local stress concentration in surrounding rock
	Multi destressing holes cluster blasting	Used to solve the problem of large in-situ stress concentration zone.
Position of destressing	Side wall destress blasting	Applied on the surrounding rocks of the two sides walls of roadway to maintain the stability of mine roadway.
	Floor destress blasting	Applied at the shallow floor of drift (mine roadway) to destress the floor of mine roadway
	Face destress blasting	Used in face to reduce stress concentrations and to generate fractured zones in front of working face (away from working face)
Existence or absence of controlled holes	Conventional destress blasting	No controlled holes used (all holes are loaded by explosives)
	Controlled destress blasting	Use some controlled holes (some holes are not loaded by explosives). i.e. a combination of unloaded (uncharged) holes and loaded holes are used

4. MECHANISM OF DESTRESS BLASTING

4.1 Destress blasting in working face and Mine Roadway

As mining depth increases, the ground stress also increases subsequently, especially in surrounding rock mass of working face. In the absence of stress control measures, the rockburst can occur consequently. The accumulated stress in surrounding rock mass of the stope which is a rockburst triggering factor is decreased by the application of destress blasting technique through destressing hole drilling and loading explosives.

Destress blasting technique is applied by drilling and blasting within high stressed zone with reasonable smaller loaded explosive before the face advancement. Prior the application of this technique, great attention must be paid on the type and expiration date of explosives prepared to be used. During the application of this technique, great attention must also be paid on the location and spacing of destressing holes, length, diameter, and number of destressing holes, length of loaded part of destressing hole, and the total number of loaded explosives (Konicek, 2011).

Generally, destressing hole is loaded at the bottom, the length of loaded part of destressing hole should be smaller than the half of destressing hole, and the length of destressing hole should be greater than the regular production blasthole. In this context, the terminology of *destressing hole* refers to the blasthole designed and drilled for destress blasting application, while *regular production blasthole* refers to the blasthole designed and drilled for usual blasting practice. From the Fig 2a, b and c, the mechanism of destress blasting showing the state of stress before and after destress blasting.

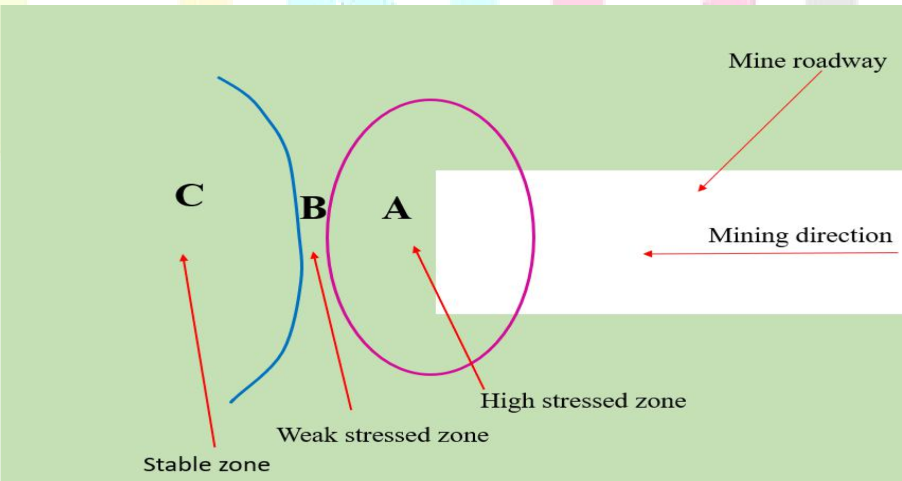

Fig.1a, Schematic diagram showing stress state before destress blasting

From this Fig **1a**, three zones **A, B** and **C** are indicated to represent the state of stress before the application of destress blasting technique. The first zone is *High stressed zone* represented by **A**. In this zone, there is high stress concentration induced by mining activities and previous destress blasting. This zone is composed by working face and its surrounding rock. For safe working, it needs to be destressed before the face advancement. The second zone is *Weak stressed zone* represented by **B**. In this zone, there is a weak stress concentration because it is the smallest transitional zone between the high stressed zone and stable zone. By the mining advancement, this zone will be highly stressed soon by the mining induced stress. The third zone is *Stable zone* represented by **C**. To call this it a stable zone does not mean that there is no stress, however it has only pre-mining stress. It is a zone which is not yet affected by the mining activities and previous destress blasting, but by the mining advancement, it will be affected latter.

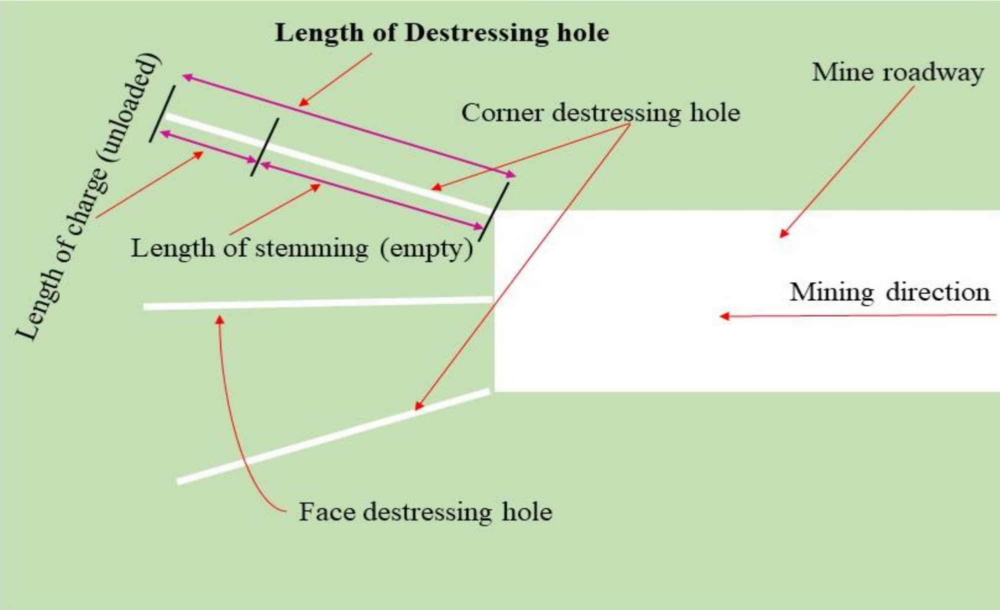

Fig.1b, Schematic diagram showing the drilled face and corner destressing holes

This Fig **1b**, representing the corner and face destressing holes with their respective parts. drilling destressing holes is a starting point of destress blasting. High stress concentration in surrounding rock of face is the main cause of rockburst and other dynamic disasters. Releasing, transferring and redistributing high stress in surrounding rock ahead of working face is an effective means to prevent face bursting as shown on Fig **1c**.

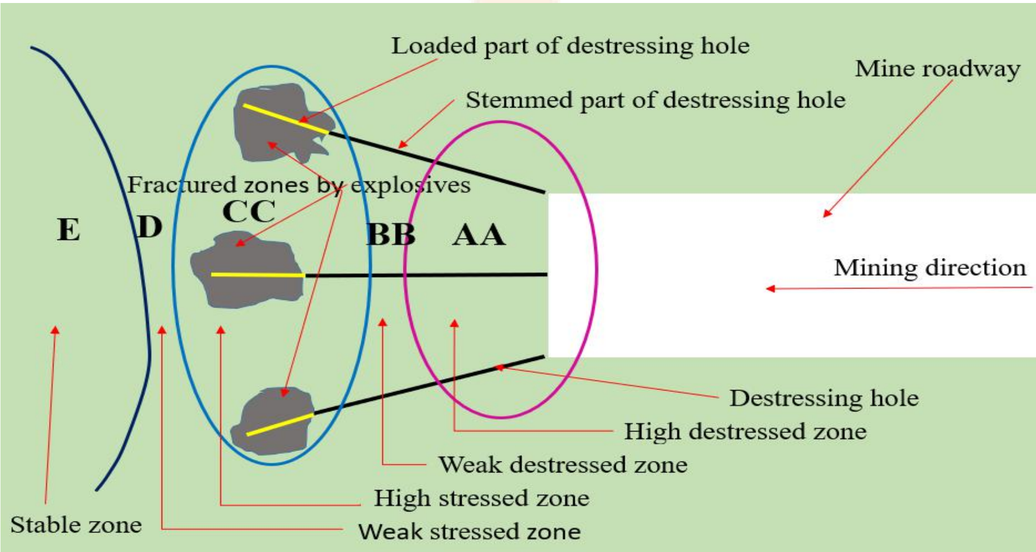

Fig 2c. Schematic diagram showing the stress state after destress blasting

From this Fig **1c**, five zones **AA, BB, CC, D, E** and **F** are indicated to represent the state of stress after the application of destress blasting technique**.** First zone is *High destressed zone* represented by **AA**, which is the former high stressed zone **A** before the application of destress blasting**.** In this zone, the former high stress concentration was transferred by destress blasting from zone **A** to zone **C**. Meaning that the high stress was transferred far away from the surrounding rock of working face.

The second zone is *Weak destressed zone* represented by **BB**, which is the former weak stressed zone **B** before the application of destress blasting. Zone **BB** is the smallest transitional zone between the high destressed zone **AA** and high stressed zone **CC**. Because this zone **BB** is not too far from explosives charge, therefore it may have little effect from damaged zone (high stressed zone **CC**) induced by blasting. The third zone is *High stressed zone* represented by **CC**, which is the former stable zone **C** before the application of destress blasting. This zone **CC** has received and accumulated the stress transferred by destress blasting from the surrounding rock of working face.

The fourth zone is *Weak stressed zone* represented by **D**. It is same as the zone **B** before destress blasting. In this zone, there is a weak stress concentration because it is the smallest transitional zone between the high stressed zone **CC** and stable zone **E**. Because this zone **D** is not too far from explosives charge, therefore, it may have little effect from damaged zone (high stressed zone **CC**) induced by blasting. By the mining advancement, this zone will be highly stressed soon by the mining induced stress.

The fifth zone is *Stable zone* represented by **E**. It is same as the zone **C** before destress blasting. To call it a stable zone does not mean that there is no stress, however it has only pre-mining stress. It is a zone which is not yet affected by the mining activities and previous destress blasting, but by the mining advancement, it will be affected latter. From the Figs **2a**, **b** and **c**, it can be concluded that, the high stress concentration in surrounding rock mass of the working face (zone **A**) are decreased after the application of destress blasting.

For mine roadway (drift) destress blasting, see the Fig 2. During the development of underground mine roadway in hard rock, such as deep drifting (ramp, drift and cross cuts) may suffer from face bursting or floor bursting, resulting from mining induced stress in brittle rock mass (Tang, 2000; Saharan, 2004; Saharan and Mitri, 2011). Even if the protective pillars bear the gravity of the upper rock mass, however, they can be squeezed by the horizontal stresses, meaning that the mine roadway is in high stress state. Under the action of the stress concentration of the protective pillars, the roadway on both sides of the pillars appear serious floor heave phenomenon, which is prone to rock burst and other dynamic disasters.

In order to reduce this stress, destress blasting technique is applied by drilling destressing holes on the both side of the roadway and carry out blasting (refer to Fig 2), which releases the elastic deformation energy accumulated in the surrounding rock, redistributes the high stresses by transferring them to away from the roadway, so that the surrounding rock of the two sides walls of roadway and the floor kept in the destressed zone, thus protecting the stability of the roadway. During deep shaft excavation, strain burst can occur as floor bursting, or wall spalling. The employment of floor destress blasting as a part of mining circle can play a great role in preventing or mitigating the floor bursting or wall spalling (Tang, 2000; Saharan, 2004; Saharan and Mitri, 2011).

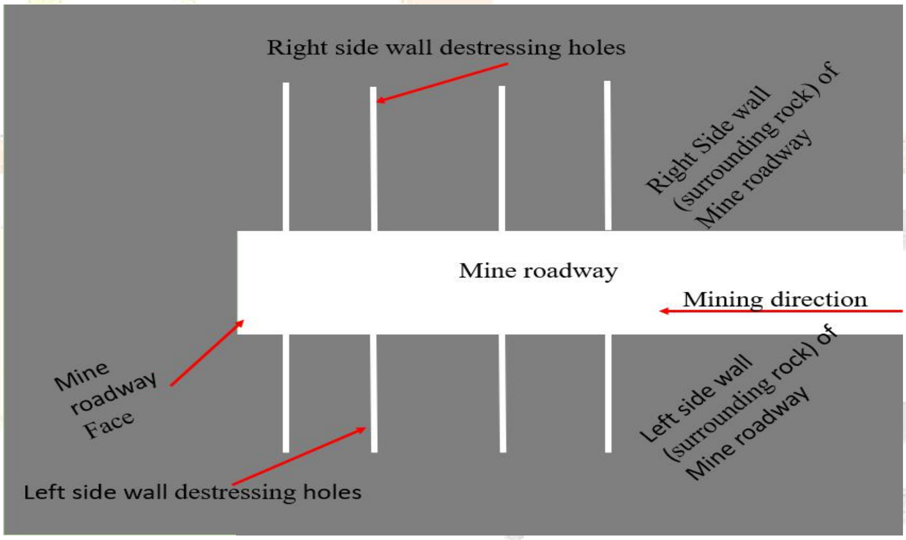

Fig 2. Schematic diagram showing side wall destressing holes pattern of mine roadway

According to Konicek (2011), a well befitted destress rock blasting (location and spacing of destressing holes, diameter, number of destressing holes, length of loaded part of destressing hole, and the total number of loaded explosives) decreases the strength of rocks and discharges the high stress concentration in the zone closer to the blasting area. In this circumstance, the main objectives of destress blasting proved to be decreasing the strength of competent rock strata and decreasing their effective modulus of elasticity, and stress release.

4.1 Features from the Figure 1a, c, b, and Figure 2

From the Figs **1a, c, b**, and Fig **2**, the following features can be determined:
Destressing hole: Refers to the blasthole designed and drilled for destress blasting application.

Corner destressing hole: The entire destress blastholes arranged in the corners of drift.
Face destressing hole: The entire destress blastholes arranged ahead of working face or stope.
Length of destressing hole: A specific length of the entire destress blastholes designed and drilled to be loaded by explosives and subsequently filled by the stems (Length of charge +Length of stemming) for the purpose of destress blasting application.
Length of stemming: A part of entire destressing hole designed to be filled by the stems, which extends from the working face to the beginning of a part designed to be loaded by the explosives for the purpose of destress blasting application.
Length of charge (prior to loading): A part of entire destressing hole designed to be loaded by the explosives, which extends from the end of stemming part to the bottom of the entire destressing hole.
Loaded part: A part of the entire destressing hole already charged by the explosives.
Stemmed part: A part of the entire destressing hole already filled by the stems (such as drill cuttings).
Fractured zones: Zones with rock mass fractured by explosives after being blasted.
High destressed zone: A zone closer to the working face from which the high stress concentration has been transferred ahead of the working face.
Weak destressed zone: A transitional zone between a high destressed zone and high stressed zone.
High stressed zone (before on shift destress blasting): It is a zone with high stress concentration induced by mining activities and previous destress blasting.
High stressed zone (after destress blasting): A zone closer to the loaded part in which the high stress concentration has been transferred from the zone closer to the working face. It is also a zone in which rock mass has been fractured by explosives after being fired for the purpose of destress blasting application.
Stable zone: A zone with only pre-mining stress, which is not yet affected by the mining activities and previous destress blasting, but by the mining advancement, it will be affected latter.

5. SUITABLE AREAS FOR THE APPLICATION OF DESTRESS BLASTING

Being a wise for a successful application of destress blasting technique, the first step is to recognise where it is required to be carried out. During the application of this technique, great attention must be paid on the location, because wrong location can provoke further problems. This tactical measure is applied in deep mining or other excavation by drilling destressing holes in high stressed zone and carry out blasting, which releases the elastic deformation energy accumulated in the surrounding rock, redistributes the stresses by transferring them to the surrounding rock away from the face. Below is the summary of suitable areas for the application of destress blasting technique.

5.1 Tunnelling

Tunnelling work is also one of underground workings which can suffer from rockbursting. Tunnel excavation in unfavourable condition such as great depth, high horizontal stress, and occurrence of competent rock can suffer from rockbursting, Such as Tunnel of Jinping II Hydropower Station in Sichuan province, China (Jiang et al., 2010; Zhang et al., 2012; Feng et al., 2014); Tianshengqiao II Hydropower Station in Guangxi Province, China (Lee et al., 1996; Li et al., 2007); Guancunba tunnel of Chengdu-Kunming railway, Kunming section; The Gotthard Base Tunnel in Switzerland (Husen et al., 2012); Parbati II headrace tunnel in Kullu district in Himachal, India. Example: In China, Tunnel of Jinping II Hydropower Station in Sichuan province, has used destress blasting technique to control rock burst during excavation.

5.2 Underground mine roadways

During the development of underground roadways in hard rock, such as deep drifting (ramp, drift and cross cuts) may suffer from face bursting or floor bursting, resulting from mining induced stress in brittle rock mass. Therefore, the application of destress blasting technique can transfer the stress from the corner of drift and working face to ahead of working face and drift corner; During deep shaft excavation, strain burst can occur as floor bursting, or wall spalling. The employment of floor destress blasting as a part of mining circle can play a great role in preventing or mitigating the floor bursting or wall spalling (Tang, 2000; Saharan, 2004; Saharan and Mitri, 2011).

5.3 Underground mine pillars

The application of conventional cut and fill, overhand exploitation of small lifts of 2-3 can probably lead to the high concentration of stress in crown pillars, especially above the face, therefore, in order to safe working, destress blasting of crown pillar is very essential (Hedley, 1992;Tang, 2000; Saharan, 2004; Saharan and Mitri, 2011). The typical cases of practical application of crown pillars destressing at Camplebell mine, Lucky Friday mine, Creighton mine, and Macassa mine, were well explained by Hedley, (1992). Different mining techniques such as: (cut and fill stoping, shrinkage stopes and sublevel stoping) involve the sill pillars. In order to safe exploitation of resources, destress blasting of sill pillar is very essential (Hedley, 1992; Tang, 2000; Saharan, 2004; Saharan and Mitri, 2011).

5.4 Underground mining method

As some mining methods such as: Undercut and fill mining, and longwall mining are more associated by high stress, therefore destress blasting technique is more suitable to control the stress where such mining methods are being employed (Hedley, 1992; Tang, 2000; Saharan, 2004; Saharan and Mitri, 2011).

6. SOME CHALLENGES IN THE APPLICATION OF DESTRESS BLASTING

Despite the importance of destress blasting technique in controlling rockburst occurrence in deep mines and other excavation projects, there are some usual challenges which can arise during its application, and other challenges related to unreasonable application, both are summarized below:

Over destress blasting: The energy of blasting is greater than the energy required for relieving the stress, which leads to the instability of the working face. *Incomplete destress blasting*: Cannot completely relieve the high stress in surrounding rock, and may cause further instability of surrounding rock, resulting in rock burst and other ground pressure problems. *Amount of explosive*: Proper application of destress blasting reduces the stress in the area where rock burst may occur, transferring them away from the face, and reducing the strain energy of surrounding rock, however, it is not easy to determine the amount of explosive needed for sufficient destress blasting. *Excessive ground vibration* due to the charge diameter and charge coupling within destress holes: The larger the blast hole diameter, the greater the ground disturbance at the working face. Well coupled charges in the destress hole create higher vibrations than do decoupled charges. *Misfires*: Application of destress blasting involves the use of explosives as in the usual rock blasting practice, therefore, the misfires which can occur during the application of destress blasting, can lead to the hazardous in next mining step (Tang, 2000). *Mining cost*: Unreasonable application of destress blasting can lead to the unexpected increase of mining cost. *Rockburst occurrence:* As some mining methods can cause rockburst occurrence, the improper application of destress blasting can also provoke the occurrence of rockburst itself. *Excessive airblast*: Insufficient length or quality of stemming material, both of which promote blow-outs: Improper size and angularity of stem material will promote low friction sidewall forces that cannot withstand detonation pressures, Stem lengths that are too short will most likely be ejected. *Timing*: The application of destress blasting is conducted on time conditional i.e: when it is needed. If it is carried out too late (when the stress is beyond the controlleable point), it may end up with zero safety result, hence on shift bursting (Tang, 2000).

7. SUMMARY AND CONCLUSION

Destress blasting is one of the essential techniques to control the rockburst hazards in deep mines through the principle of stress transfer. From this review:

Despite the factors which contribute to the increase of ground stress, it can be seen that all definitions of destress blasting technique given by different researchers focus on ground stress control as the major triggering factor of rockburst in deep mines. The conceptual model of destress rock blasting technique was put forward based on the rockburst model. This technique was applied in different countries such as South Africa, Canada, USA, China, Czech Republic, Finland, Sweden, Japan, on so on. From the view point of mechanism of destress blasting, it can be seen that, the high stresses concentration in surrounding rock mass of the underground mine working face are decreased after the application of destress blasting.

The suitable areas for the application of destress blasting were reviewed as Tunnel excavation in unfavourable condition (such as great depth, high horizontal stress, and occurrence of competent rock which can suffer from rockbursting), Underground mine roadways **(**ramp, drift, cross cuts, and deep shaft excavation), Underground mine pillars (such as crown and sill pillars), and Underground mining method such as: Undercut and fill mining, and longwall mining method.

The possible challenges which may arise during its field application, includes: Over destress blasting, Incomplete destress blasting, Imbalance in amount of explosive and field to be applied for, Excessive ground vibration due to the charge diameter and charge coupling within destress holes; Misfires, Increase of mining cost, Rockburst occurrence, Excessive airblast, and time conditional. Despite the application of destress blasting, the increase of rock burst occurrence is a severe problem to the engineers and researchers. A well mastering the fractures growth caused by poly axial stress regime and the appropriate use of explosive energy for effective fracture creation and growth are pointed out as important attention to enhance destress blasting technique

It is substantiated that destress blasting is the best reliable proactive means to control the threats of rockburst if reasonably employed in real place, manner and timing. The results of this technique can be very good if the proper way of its application is mastered. Therefore, during its field application, a great attention must be paid on the location and spacing of destressing holes, length, diameter, and number of destressing holes, length of loaded part of destressing hole, and the total number of loaded explosives. With this notion in mind, this technique can be considered to be a very important and necessary part of regular mining cycle as the objective of destress blasting is to create a safety barrier between the excavation boundary and the high stress zones.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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